

ORIGINAL

Application Based on

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ORGANIC ELEMENT FOR ELECTROLUMINESCENT DEVICES

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ORGANIC ELEMENT FOR ELECTROLUMINESCENT DEVICES

FIELD OF THE INVENTION

This invention relates to an electroluminescent (EL) device comprising an ethynyl stabilizing compound that can provide good operational stability.

BACKGROUND OF THE INVENTION

While organic electroluminescent (EL) devices have been known for over two decades, their performance limitations have represented a barrier to many desirable applications. In simplest form, an organic EL device is comprised of an anode for hole injection, a cathode for electron injection, and an organic medium sandwiched between these electrodes to support charge recombination that yields emission of light. These devices are also commonly referred to as organic light-emitting diodes, or OLEDs. Representative of earlier organic EL devices are Gurnee et al. US 3,172,862, issued Mar. 9, 1965; Gurnee US 3,173,050, issued Mar. 9, 1965; Dresner, "Double Injection Electroluminescence in Anthracene", *RCA Review*, 30, 322-334, (1969); and Dresner US 3,710,167, issued Jan. 9, 1973. The organic layers in these devices, usually composed of a polycyclic aromatic hydrocarbon, were very thick (much greater than 1 μm). Consequently, operating voltages were very high, often greater than 100V.

More recent organic EL devices include an organic EL element consisting of extremely thin layers (e.g., less than 1.0 μm) between the anode and the cathode. Herein, the term "organic EL element" encompasses the layers between the anode and cathode. Reducing the thickness lowered the resistance of the organic layer and has enabled devices that operate at much lower voltage. In a basic two-layer EL device structure, described first in US 4,356,429, one organic layer of the EL element adjacent to the anode is specifically chosen to transport holes, and therefore, it is referred to as the hole-transporting layer, and the other organic layer is specifically chosen to transport electrons, and is referred to as the

electron-transporting layer. Recombination of the injected holes and electrons within the organic EL element results in efficient electroluminescence.

There have also been proposed three-layer organic EL devices that contain an organic light-emitting layer (LEL) between the hole-transporting layer and electron-transporting layer, such as that disclosed by Tang et al (*J. Applied Physics*, **65**, Pages 3610-3616, (1989)). The light-emitting layer commonly consists of a host material doped with a guest material, also known as a dopant. Still further, there has been proposed in US 4,769,292 a four-layer EL element comprising a hole-injecting layer (HIL), a hole-transporting layer (HTL), a light-emitting layer (LEL) and an electron transport/injection layer (ETL). These structures have resulted in improved device efficiency.

Since these early inventions, further improvements in device materials have resulted in improved performance in attributes such as color, stability, luminance efficiency and manufacturability, e.g., as disclosed in US 5,061,569, US 5,409,783, US 5,554,450, US 5,593,788, US 5,683,823, US 5,908,581, US 5,928,802, US 6,020,078, and US 6,208,077, amongst others.

Notwithstanding these developments, there are continuing needs for organic EL device components, such as light-emitting materials that will provide high luminance efficiencies combined with long lifetimes. In particular, there is a need to be able to adjust the emission wavelength of the light-emitting material for various applications. For example, in addition to the need for blue, green, and red light-emitting materials there is a need for blue-green, yellow and orange light-emitting materials in order to formulate white-light emitting electroluminescent devices. For example, a device can emit white light by emitting a combination of colors, such as blue-green light and red light or a combination of blue light and orange light.

White EL devices can be used with color filters in full-color display devices. They can also be used with color filters in other multicolor or functional-color display devices. White EL devices for use in such display devices are easy to manufacture, and they produce reliable white light in each pixel of the displays. Although the OLEDs are referred to as white they can appear white or off-white,

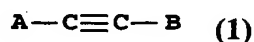
the CIE coordinates of the light emitted by the OLED are less important than the requirement that the spectral components passed by each of the color filters be present with sufficient intensity in that light. The devices must also have good stability in long-term operation. That is, as the devices are operated for extended periods of time, the luminance of the devices should decrease as little as possible. There is a need for new materials that improve the operational stability of devices.

Certain acetylenic materials have been reported to have interesting spectral properties, for example, see S. Akiyama, K. Nakashima, S. Nakatsuji, and M. Nakagawa, *Dyes and Pigments*, **13**, 117, 1990. However, with a few exceptions, acetylenic materials have not found widespread use in EL devices. In one example, G. Yu, Y. Liu, X. Zhan, H. Li, M. Yang, D. Zhu, *Thin Solid Films*, **363** 126 (2000), have reported emission from a series of aryl-substituted polyacetylenes, poly(phenylacetylene), poly(p-ethynylphenylacetylene), poly(p-phenylethynylphenylacetylene)), and poly[p-(2-thiophenylethynyl)phenylacetylene]. Single layer light-emitting diodes using these materials as an emissive layer were fabricated. T. Shinji, A. Goro, T. Akira, and I. Jun, JP 2000021571, describe materials to be included in a light-emitting layer. These materials may include a compound that has two acetylenic groups.

Despite these advances, there is a continuing need for new readily synthesized materials that exhibit good luminance efficiency and operational stability. Improved operational stability in OLED devices will allow their use in more applications.

SUMMARY OF THE INVENTION

An electroluminescent device comprises a cathode, an anode, and therebetween a layer containing a host material and an ethynyl compound of Formula (1):



in an amount sufficient to stabilize the device wherein A and B represent independently selected fused carbocyclic ring groups. The invention also includes a display or lighting device and a process for emitting light employing the OLED.

The device of the invention exhibits good luminance efficiency and
5 operational stability.

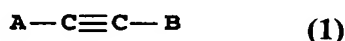
BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross-section of a typical OLED device in which this invention may be used.

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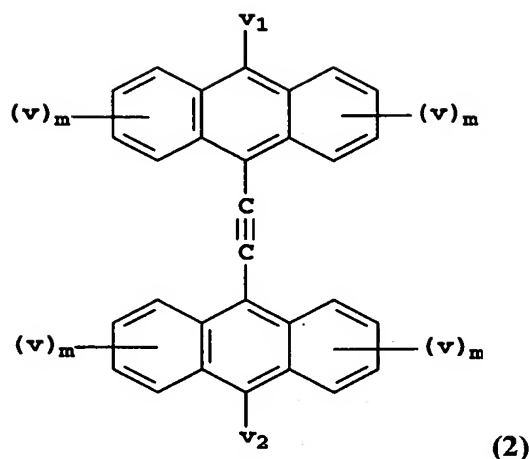
DETAILED DESCRIPTION OF THE INVENTION

In one embodiment an electroluminescent device of the invention is a multilayer device comprising a cathode, an anode, charge-injecting layers (if necessary), charge-transporting layers, and a light-emitting layer (LEL) containing
15 a host material and a second material comprising a compound of Formula (1).



In Formula (1), A and B represent independently selected fused carbocyclic ring
20 groups, for example, naphthalene groups, such as 1-naphthyl, 2-naphthyl, and 4-phenyl-1-naphthyl group or anthracene groups, such as 9-anthryl and 10-phenyl-9-anthryl groups or phenanthrene groups. Suitably, A may represent an anthracene group and B may represent a naphthalene group. Desirably both A and B represent independently selected anthracene groups. In one suitable embodiment,
25 A and B represent 10-phenyl-9-anthryl groups. In one desirable embodiment, Formula (1) contains only one ethynyl bond.

In one embodiment, the electroluminescent device includes a light-emitting layer (LEL) containing a host material and an ethynyl compound comprising a compound of Formula (2).

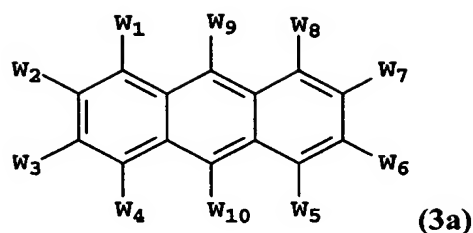


In Formula (2), m and n are 0-4. Each v independently represents a substituent, such as a phenyl group or a tolyl group. Adjacent substituents may combine to form rings, such as fused benzene ring groups.. In the formula, v₁ and v₂ independently represent hydrogen or a substituent, such as a phenyl ring group or an alkyl group. Suitably v₁ and v₂ may both represent independently selected aromatic ring groups, such as a furan ring group or a thiophene ring group. Desirably, v₁ and v₂ both represent independently selected phenyl ring groups, such as naphthyl ring group or a tolyl group.

Suitably the material of Formula (1) is present in an amount between 0.5 and 20% by weight of the layer. Typically it is between 0.5 and 8% by weight of the emitting layer.

Embodiments of the Formula (1) materials useful in the invention can provide a range of hues. Embodiments of the light-emitting materials especially useful in the invention provide an emitted light having a blue-green or green hue. In another embodiment, Formula (1) materials useful in the invention are used in an electroluminescent device that emits white light.

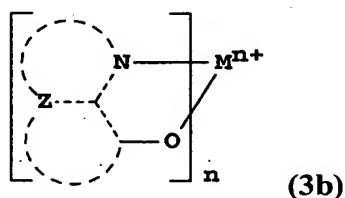
Desirable hosts include those based on an anthracene compound. In one desirable embodiment the host is represented by Formula (3a).



In Formula (3a), w_1 - w_{10} independently represent hydrogen or an independently selected substituent, provided that two adjacent substituents can
 5 combine to form rings. In one suitable embodiment, w_9 and w_{10} independently represent naphthyl groups. In another desirable embodiment, w_9 and w_{10} represent a naphthyl group and a biphenyl group.

Particular examples of hosts are 9,10-di-(2-naphthyl)anthracene, 2-*t*-butyl-9,10-di-(2-naphthyl)anthracene, 9-(4-biphenyl)-10-(2-naphthyl)anthracene
 10 and 9-(4-biphenyl)-10-(1-naphthyl)anthracene. Preferably, the host is selected such that the host absorbs light at a shorter wavelength than the dopant and the emission spectrum of the host overlaps with the absorption spectrum of the dopant.

Metal complexes of 8-hydroxyquinoline and similar derivatives,
 15 also known as metal-chelated oxinoid compounds, Formula (3b), constitute another class of useful host compounds.



wherein

20 M represents a metal;

n is an integer of from 1 to 4; and

Z independently in each occurrence represents the atoms completing a nucleus having at least two fused aromatic rings.

The metal can be monovalent, divalent, trivalent, or tetravalent metal. The metal can, for example, be an alkali metal, such as lithium, sodium, or potassium; an alkaline earth metal, such as magnesium or calcium; a trivalent metal, such as aluminum or gallium, or another metal such as zinc or zirconium.

5 Generally any monovalent, divalent, trivalent, or tetravalent metal known to be a useful chelating metal can be employed.

Z completes a heterocyclic nucleus containing at least two fused aromatic rings, at least one of which is an azole or azine ring. Additional rings, including both aliphatic and aromatic rings, can be fused with the two required
10 rings, if required. To avoid adding molecular bulk without improving on function the number of ring atoms is usually maintained at 18 or less.

Desirably, the metal is trivalent aluminum and Z represents the atoms necessary to complete a quinoline group.

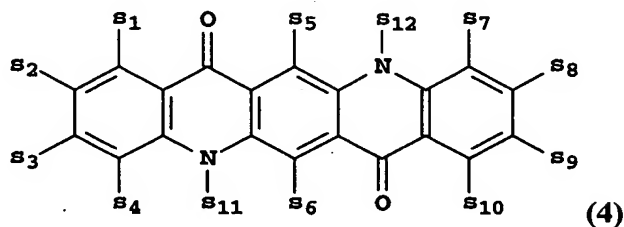
Illustrative of useful chelated oxinoid compounds are aluminum
15 trisoxine [alias, tris(8-quinolinolato)aluminum(III)], magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)], bis[benzo{f}-8-quinolinolato]zinc (II), bis(2-methyl-8-quinolinolato)aluminum(III)- μ -oxo-bis(2-methyl-8-quinolinolato)aluminum(III), indium trisoxine [alias, tris(8-quinolinolato)indium], aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato) aluminum(III)], lithium
20 oxine [alias, (8-quinolinolato)lithium(I)], gallium oxine [alias, tris(8-quinolinolato)gallium(III)], zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)].

In one embodiment, the light-emitting layer includes a host material, a second material comprising a compound of Formula (1), and a third
25 material that emits light. In one embodiment the third material emits green light. In one embodiment the compound of Formula (1) does not emit light.

Suitably the material of third material is present in an amount between 0.5 and 20% by weight of the layer. Typically it is between 0.5 and 8% by weight of the emitting layer.

30 A particularly useful class of green light-emitting material includes quinacridone compounds. Useful quinacridones are described US 20040001969

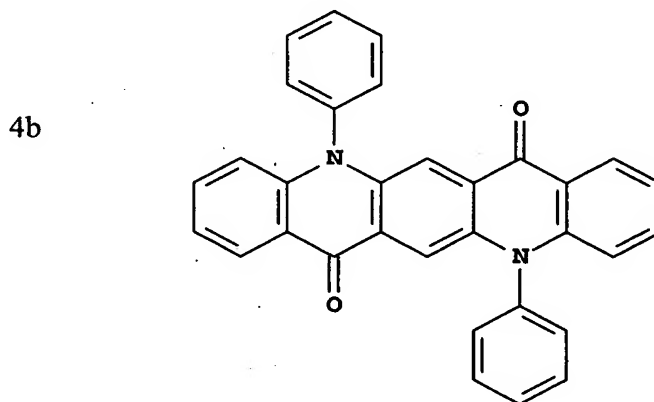
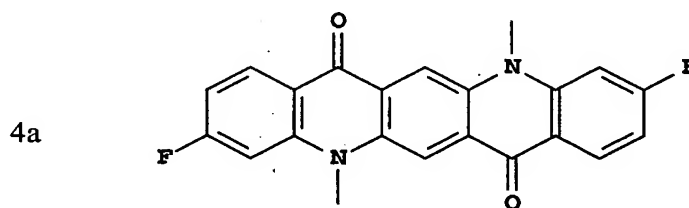
A1, US6664396 B1, US 5,593,788, and JP 09-13026A. In one embodiment, the third material in the light-emitting layer is a quinacridone compound represented by Formula (4).

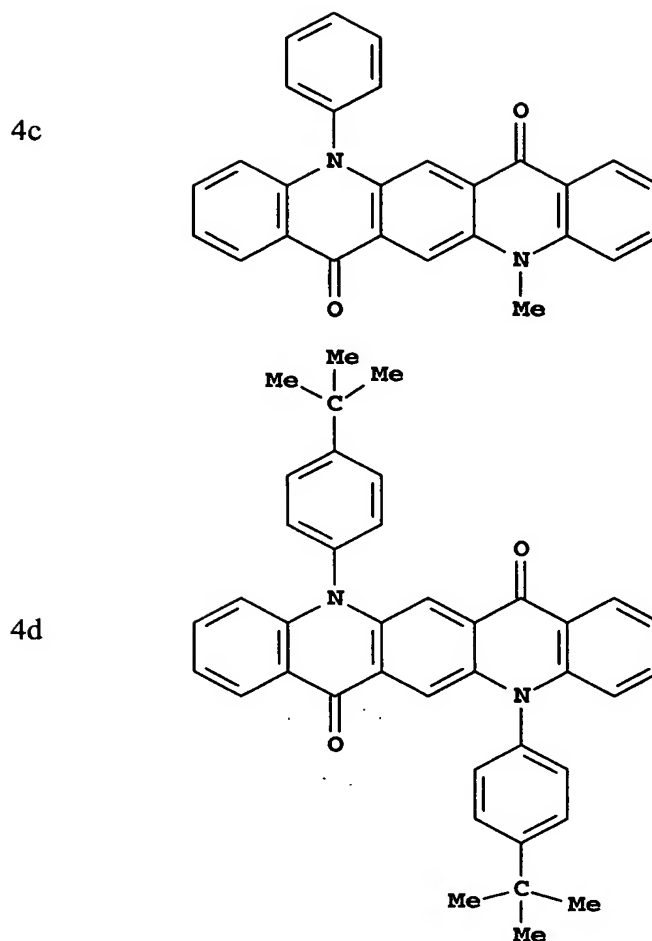


5 In Formula (4), $s_1 - s_{10}$ independently represent hydrogen or an independently selected substituent, such as a phenyl group, a tolyl group, a halogen such as F, or an alkyl group, such as a methyl group. Adjacent substituents may combine to form rings, such as fused benzene ring groups.

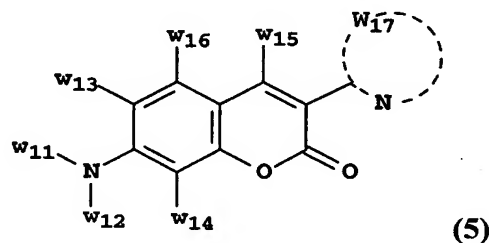
10 In Formula (4), s_{11} and s_{12} independently represent an alkyl group or an aromatic group. In one suitable embodiment, s_{11} and s_{12} independently represent a phenyl ring group, such as a phenyl ring or a tolyl ring.

Illustrative examples of useful quinacridone compounds are shown below.



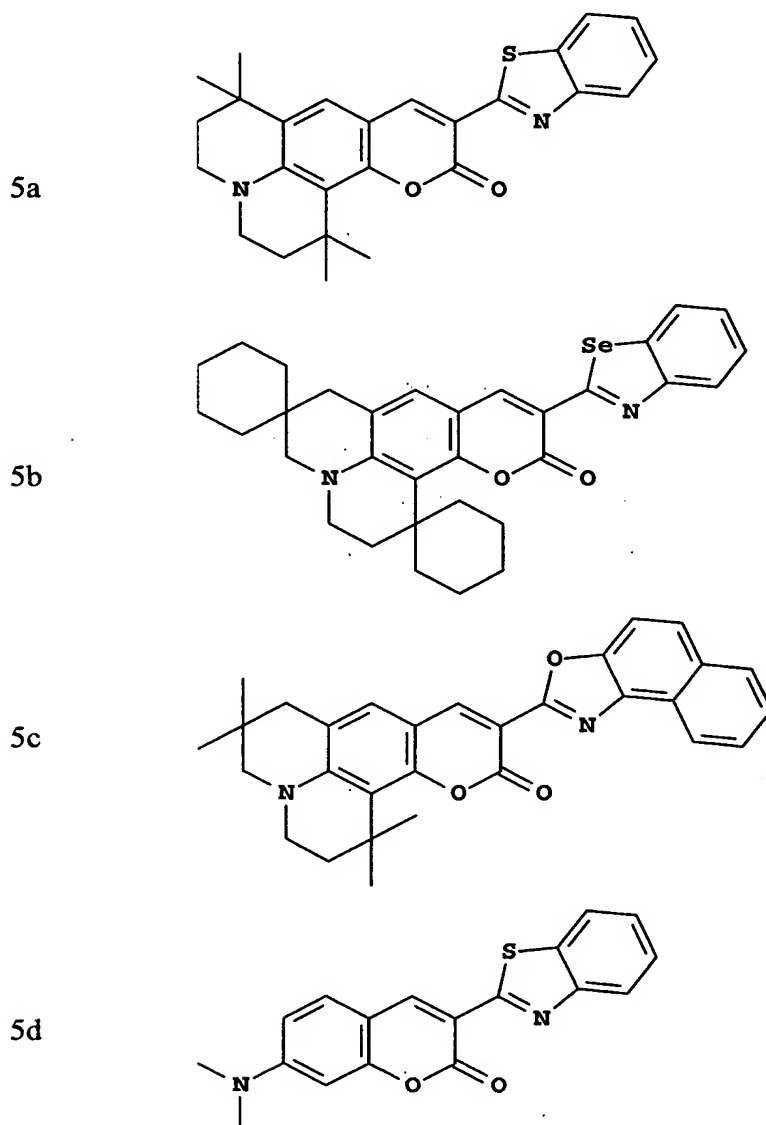


Another particularly useful class of green light-emitting materials includes coumarin compounds. For example, useful coumarins are described in Tang et al., US 4,769,292 and US 6,020,078. In one embodiment of the invention, the third material in the light-emitting layer is a coumarin represented by Formula (5).



In Formula (5), w_{11} and w_{12} represent an independently selected substituent, such as an alkyl group or aryl group, provided w_{11} and w_{12} may

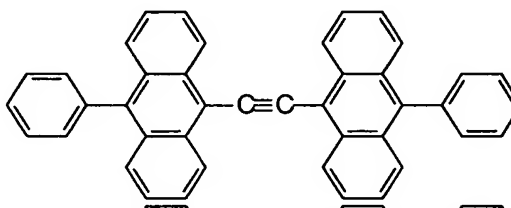
combine with each other or with w_{13} and w_{14} to form rings. Desirably w_{11} and w_{12} represent independently selected alkyl groups, provided w_{11} and w_{12} may combine with each other or with w_{13} and w_{14} to form saturated rings. In Formula (5), $w_{13} - w_{16}$ independently represent hydrogen or an independently selected substituent, such as phenyl ring group or a methyl group. Adjacent substituents may combine to form rings, such as fused benzene rings. In Formula (5), w_{17} represents the atoms necessary to complete a heteroaromatic ring, such as a benzothiazole ring group. Illustrative examples of useful coumarin compounds are shown below.



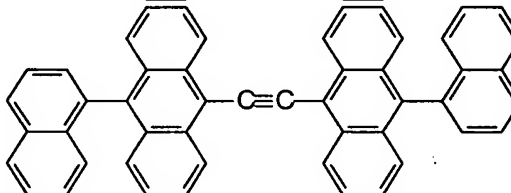
Compounds of Formula (1) can be prepared by various methods known in the literature, for example, see D. Wellman, K. Lassila, R. West, *J. Org. Chem.*, **49**, 965 (1984), S. Akiyama, K. Nakasuji, M. Nakagawa, Masazumi, *Bull. Chem. Soc. of Japan*, **44**, 2231(1971), S. Akiyama, M. Nakagawa, *Bull. Chem. Soc. of Japan*, **43**, 3561 (1970)

Illustrative examples of compounds of Formula (1) useful in the present invention include the compounds listed below.

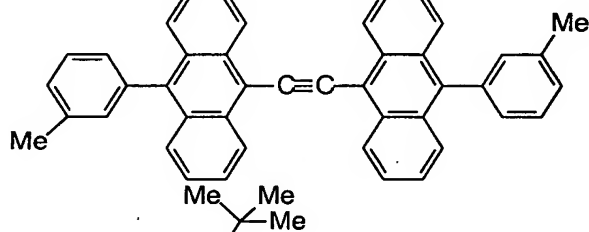
Inv-1



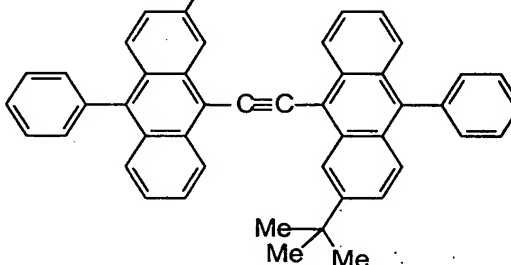
Inv-2



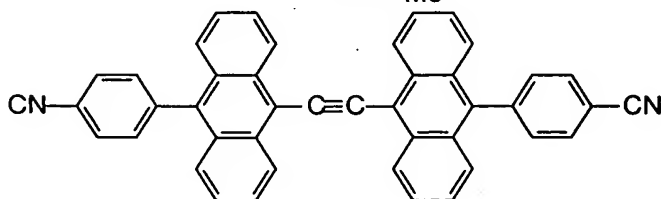
Inv-3



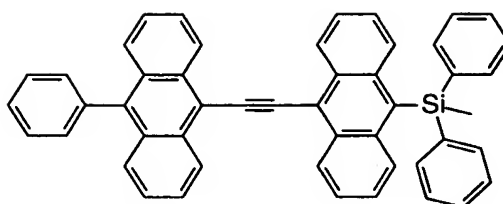
Inv-4



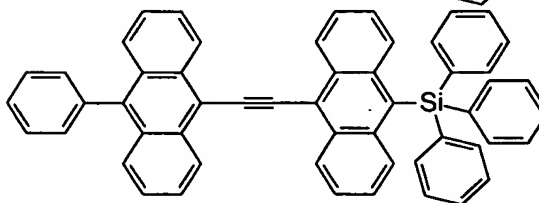
Inv-5



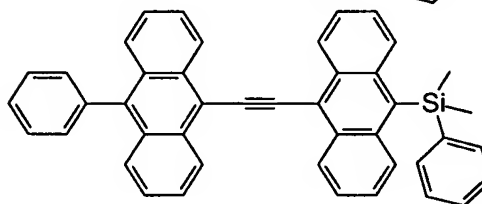
Inv-6



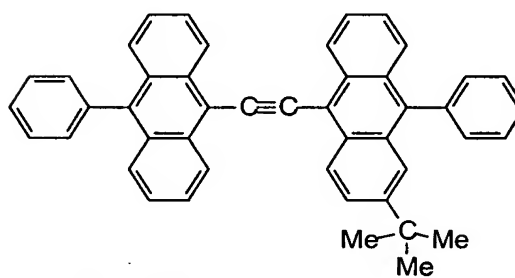
Inv-7



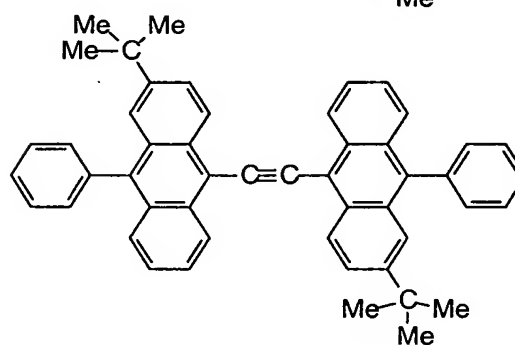
Inv-8



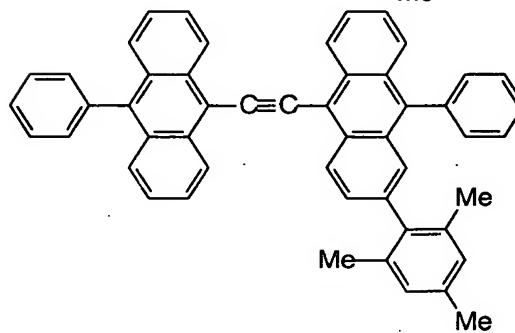
Inv-9



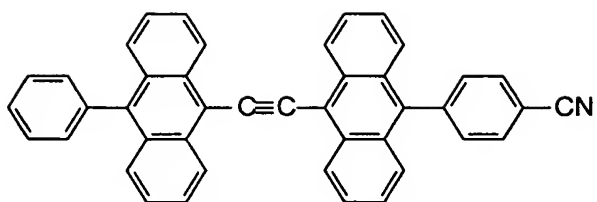
Inv-10



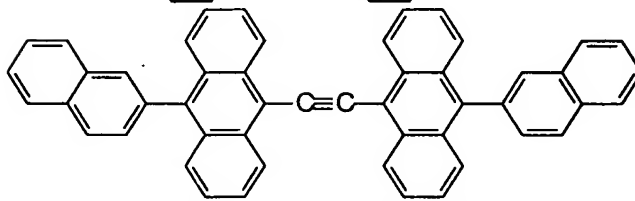
Inv-11



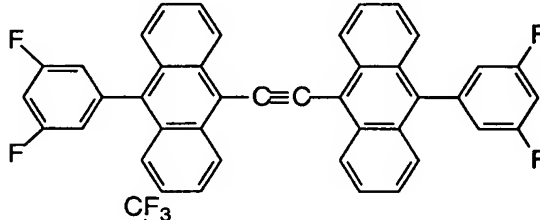
Inv-12



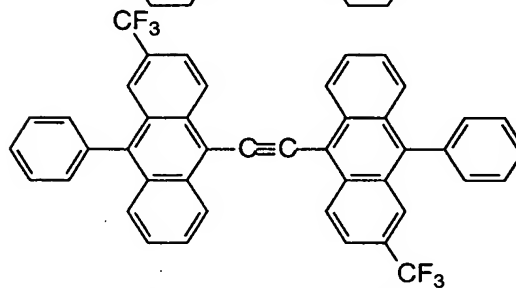
Inv-13



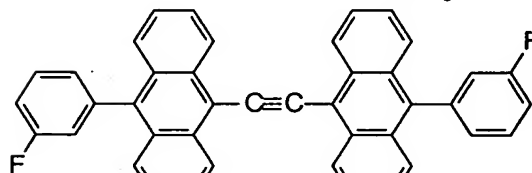
Inv-14



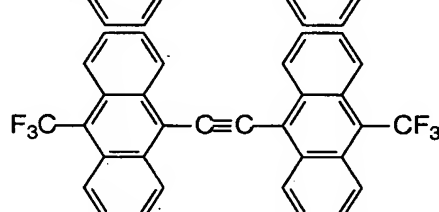
Inv-15



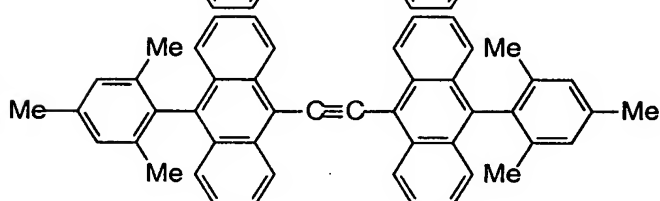
Inv-16



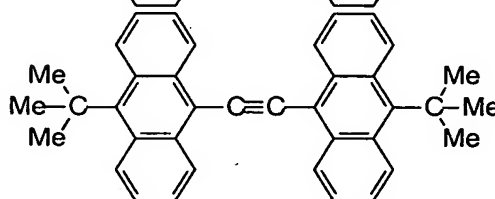
Inv-17



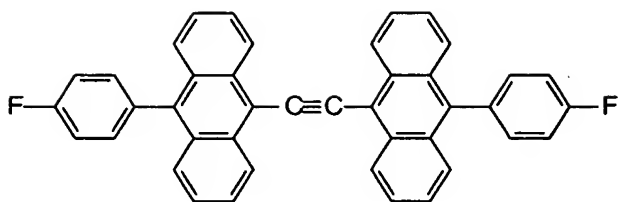
Inv-18



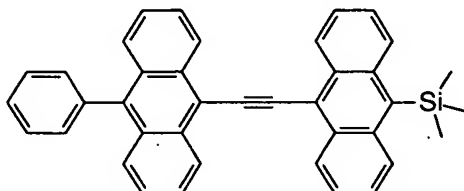
Inv-19



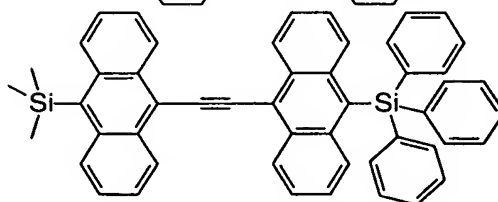
Inv-20



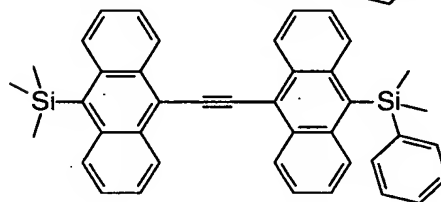
Inv-21



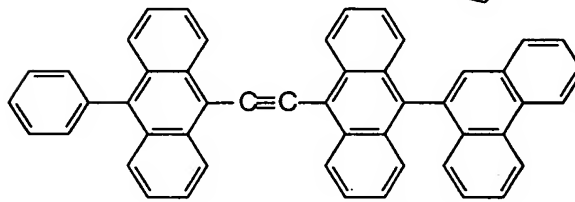
Inv-22



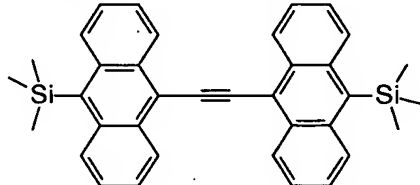
Inv-23



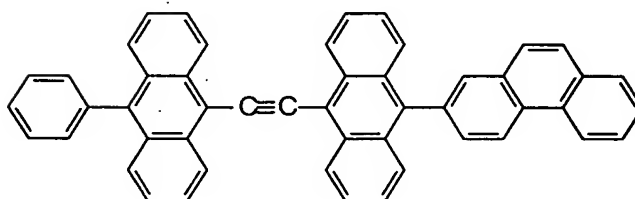
Inv-24



Inv-25



Inv-26



Embodiments of the invention provide not only good luminance efficiency but also blue-green or green hue as evidenced by the location and shape

of the emission curve of the emitted light. Embodiments of the invention can provide improved operational stability, either when used as the light-emitting material or in combination with another light-emitting material.

Unless otherwise specifically stated, use of the term "substituted" or "substituent" means any group or atom other than hydrogen. Additionally, when the term "group" is used, it means that when a substituent group contains a substitutable hydrogen, it is also intended to encompass not only the substituent's unsubstituted form, but also its form further substituted with any substituent group or groups as herein mentioned, so long as the substituent does not destroy properties necessary for device utility. Suitably, a substituent group may be halogen or may be bonded to the remainder of the molecule by an atom of carbon, silicon, oxygen, nitrogen, phosphorous, sulfur, selenium, or boron. The substituent may be, for example, halogen, such as chloro, bromo or fluoro; silicon; nitro; hydroxyl; cyano; carboxyl; or groups which may be further substituted, such as alkyl, including straight or branched chain or cyclic alkyl, such as methyl, trifluoromethyl, ethyl, *t*-butyl; alkenyl, such as ethylene, 2-butene; alkoxy, such as methoxy, ethoxy, propoxy, butoxy, 2-methoxyethoxy, *sec*-butoxy; aryl such as phenyl, 4-*t*-butylphenyl, 2,4,6-trimethylphenyl, naphthyl, biphenyl; aryloxy, such as phenoxy, 2-methylphenoxy, alpha- or beta-naphthyloxy, and 4-tolyloxy; amine, phosphate, phosphite, a heterocyclic group, a heterocyclic oxy group or a heterocyclic thio group, each of which may be substituted and which contain a 3 to 7 membered heterocyclic ring composed of carbon atoms and at least one hetero atom selected from the group consisting of oxygen, nitrogen, sulfur, phosphorous, or boron. quaternary ammonium, such as triethylammonium; quaternary phosphonium, such as triphenylphosphonium; and silyloxy, such as trimethylsilyloxy.

If desired, the substituents may themselves be further substituted one or more times with the described substituent groups. The particular substituents used may be selected by those skilled in the art to attain the desired desirable properties for a specific application and can include, for example, electron-withdrawing groups, electron-donating groups, and steric groups. When

a molecule may have two or more substituents, the substituents may be joined together to form a ring such as a fused ring unless otherwise provided. Generally, the above groups and substituents thereof may include those having up to 48 carbon atoms, typically 1 to 36 carbon atoms and usually less than 24 carbon atoms, but greater numbers are possible depending on the particular substituents selected.

General Device Architecture

The present invention can be employed in many EL device configurations using small molecule materials, oligomeric materials, polymeric materials, or combinations thereof. These include very simple structures comprising a single anode and cathode to more complex devices, such as passive matrix displays comprised of orthogonal arrays of anodes and cathodes to form pixels, and active-matrix displays where each pixel is controlled independently, for example, with thin film transistors (TFTs).

There are numerous configurations of the organic layers wherein the present invention can be successfully practiced. The essential requirements of an OLED are an anode, a cathode, and an organic light-emitting layer located between the anode and cathode. Additional layers may be employed as more fully described hereafter.

A typical structure according to the present invention and especially useful for a small molecule device, is shown in FIG. 1 and is comprised of a substrate **101**, an anode **103**, a hole-injecting layer **105**, a hole-transporting layer **107**, a light-emitting layer **109**, an electron-transporting layer **111**, and a cathode **113**. These layers are described in detail below. Note that the substrate **101** may alternatively be located adjacent to the cathode **113**, or the substrate **101** may actually constitute the anode **103** or cathode **113**. The organic layers between the anode **103** and cathode **113** are conveniently referred to as the organic EL element. Also, the total combined thickness of the organic layers is desirably less than 500 nm. If the device includes phosphorescent material, a hole-blocking layer, located between the light-emitting layer and the electron-transporting layer, may be present.

The anode 103 and cathode 113 of the OLED are connected to a voltage/current source through electrical conductors. The OLED is operated by applying a potential between the anode 103 and cathode 113 such that the anode 103 is at a more positive potential than the cathode 113. Holes are injected into the organic EL element from the anode 103 and electrons are injected into the organic EL element at the cathode 113. Enhanced device stability can sometimes be achieved when the OLED is operated in an AC mode where, for some time period in the AC cycle, the potential bias is reversed and no current flows. An example of an AC driven OLED is described in US 5,552,678.

Substrate

The OLED device of this invention is typically provided over a supporting substrate 101 where either the cathode 113 or anode 103 can be in contact with the substrate. The electrode in contact with the substrate 101 is conveniently referred to as the bottom electrode. Conventionally, the bottom electrode is the anode 103, but this invention is not limited to that configuration. The substrate 101 can either be light transmissive or opaque, depending on the intended direction of light emission. The light transmissive property is desirable for viewing the EL emission through the substrate 101. Transparent glass or plastic is commonly employed in such cases. The substrate 101 can be a complex structure comprising multiple layers of materials. This is typically the case for active matrix substrates wherein TFTs are provided below the OLED layers. It is still necessary that the substrate 101, at least in the emissive pixelated areas, be comprised of largely transparent materials such as glass or polymers. For applications where the EL emission is viewed through the top electrode, the transmissive characteristic of the bottom support is immaterial, and therefore the substrate can be light transmissive, light absorbing or light reflective. Substrates for use in this case include, but are not limited to, glass, plastic, semiconductor materials such as silicon, ceramics, and circuit board materials. Again, the substrate 101 can be a complex structure comprising multiple layers of materials such as found in active matrix TFT designs. It is necessary to provide in these device configurations a light-transparent top electrode.

Anode

When the desired electroluminescent light emission (EL) is viewed through the anode, the anode 103 should be transparent or substantially transparent to the emission of interest. Common transparent anode materials used in this invention are indium-tin oxide (ITO), indium-zinc oxide (IZO) and tin oxide, but other metal oxides can work including, but not limited to, aluminum- or indium-doped zinc oxide, magnesium-indium oxide, and nickel-tungsten oxide. In addition to these oxides, metal nitrides, such as gallium nitride, and metal selenides, such as zinc selenide, and metal sulfides, such as zinc sulfide, can be used as the anode 103. For applications where EL emission is viewed only through the cathode 113, the transmissive characteristics of the anode 103 are immaterial and any conductive material can be used, transparent, opaque or reflective. Example conductors for this application include, but are not limited to, gold, iridium, molybdenum, palladium, and platinum. Typical anode materials, transmissive or otherwise, have a work function of 4.1 eV or greater. Desired anode materials are commonly deposited by any suitable means such as evaporation, sputtering, chemical vapor deposition, or electrochemical means. Anodes can be patterned using well-known photolithographic processes. Optionally, anodes may be polished prior to application of other layers to reduce surface roughness so as to minimize short circuits or enhance reflectivity.

Cathode

When light emission is viewed solely through the anode 103, the cathode 113 used in this invention can be comprised of nearly any conductive material. Desirable materials have good film-forming properties to ensure good contact with the underlying organic layer, promote electron injection at low voltage, and have good stability. Useful cathode materials often contain a low work function metal (< 4.0 eV) or metal alloy. One useful cathode material is comprised of a Mg:Ag alloy wherein the percentage of silver is in the range of 1 to 20 %, as described in U.S. Patent No. 4,885,221. Another suitable class of cathode materials includes bilayers comprising the cathode and a thin electron-injection layer (EIL) in contact with an organic layer (e.g., an electron transporting layer (ETL)), the cathode being capped with a thicker layer of a conductive metal.

Here, the EIL preferably includes a low work function metal or metal salt, and if so, the thicker capping layer does not need to have a low work function. One such cathode is comprised of a thin layer of LiF followed by a thicker layer of Al as described in U.S. Patent No. 5,677,572. An ETL material doped with an alkali metal, for example, Li-doped Alq, is another example of a useful EIL. Other useful cathode material sets include, but are not limited to, those disclosed in U.S. Patent Nos. 5,059,861, 5,059,862, and 6,140,763.

When light emission is viewed through the cathode, the cathode **113** must be transparent or nearly transparent. For such applications, metals must be thin or one must use transparent conductive oxides, or a combination of these materials. Optically transparent cathodes have been described in more detail in US 4,885,211, US 5,247,190, JP 3,234,963, US 5,703,436, US 5,608,287, US 5,837,391, US 5,677,572, US 5,776,622, US 5,776,623, US 5,714,838, US 5,969,474, US 5,739,545, US 5,981,306, US 6,137,223, US 6,140,763, US 6,172,459, EP 1 076 368, US 6,278,236, and US 6,284,3936. Cathode materials are typically deposited by any suitable method such as evaporation, sputtering, or chemical vapor deposition. When needed, patterning can be achieved through many well known methods including, but not limited to, through-mask deposition, integral shadow masking as described in US 5,276,380 and EP 0 732 868, laser ablation, and selective chemical vapor deposition.

Hole-Injecting Layer (HIL)

A hole-injecting layer **105** may be provided between anode **103** and hole-transporting layer **107**. The hole-injecting layer can serve to improve the film formation property of subsequent organic layers and to facilitate injection of holes into the hole-transporting layer **107**. Suitable materials for use in the hole-injecting layer **105** include, but are not limited to, porphyrinic compounds as described in US 4,720,432, plasma-deposited fluorocarbon polymers as described in US 6,208,075, and some aromatic amines, for example, MTDATA (4,4',4"-tris[(3-methylphenyl)phenylamino]triphenylamine). Alternative hole-injecting materials reportedly useful in organic EL devices are described in EP 0 891 121 A1 and EP 1 029 909 A1. A hole-injection layer is conveniently

used in the present invention, and is desirably a plasma-deposited fluorocarbon polymer. The thickness of a hole-injection layer containing a plasma-deposited fluorocarbon polymer can be in the range of 0.2 nm to 15 nm and suitably in the range of 0.3 to 1.5 nm.

5 Hole-Transporting Layer (HTL)

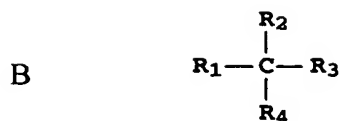
While not always necessary, it is often useful to include a hole-transporting layer in an OLED device. The hole-transporting layer 107 of the organic EL device contains at least one hole-transporting compound such as an aromatic tertiary amine, where the latter is understood to be a compound
10 containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine, diarylamine, triarylamine, or a polymeric arylamine. Exemplary monomeric triarylamine are illustrated by Klupfel et al. US 3,180,730. Other suitable triarylamine substituted
15 with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are disclosed by Brantley et al US 3,567,450 and US 3,658,520.

A more preferred class of aromatic tertiary amines is those which include at least two aromatic tertiary amine moieties as described in US 4,720,432 and US 5,061,569. Such compounds include those represented by structural
20 formula (A).



wherein Q₁ and Q₂ are independently selected aromatic tertiary amine moieties and G is a linking group such as an arylene, cycloalkylene, or alkylene group of a carbon to carbon bond. In one embodiment, at least one of Q₁ or Q₂ contains a
25 polycyclic fused ring structure, e.g., a naphthalene. When G is an aryl group, it is conveniently a phenylene, biphenylene, or naphthalene moiety.

A useful class of triarylamine satisfying structural formula (A) and containing two triarylamine moieties is represented by structural formula (B):



where

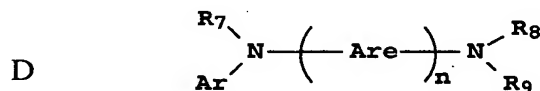
R₁ and R₂ each independently represents a hydrogen atom, an aryl group, or an alkyl group or R₁ and R₂ together represent the atoms completing a cycloalkyl group; and

- 5 R₃ and R₄ each independently represents an aryl group, which is in turn substituted with a diaryl substituted amino group, as indicated by structural formula (C):



wherein R₅ and R₆ are independently selected aryl groups. In one embodiment, at least one of R₅ or R₆ contains a polycyclic fused ring structure, e.g., a naphthalene.

- 10 Another class of aromatic tertiary amines is the tetraaryldiamines. Desirable tetraaryldiamines include two diarylamino groups, such as indicated by formula (C), linked through an arylene group. Useful tetraaryldiamines include those represented by formula (D).



wherein

- 15 each Are is an independently selected arylene group, such as a phenylene or anthracene moiety,

n is an integer of from 1 to 4, and

Ar, R₇, R₈, and R₉ are independently selected aryl groups.

- 20 In a typical embodiment, at least one of Ar, R₇, R₈, and R₉ is a polycyclic fused ring structure, e.g., a naphthalene.

The various alkyl, alkylene, aryl, and arylene moieties of the foregoing structural formulae (A), (B), (C), (D), can each in turn be substituted. Typical substituents include alkyl groups, alkoxy groups, aryl groups, aryloxy

groups, and halide such as fluoride, chloride, and bromide. The various alkyl and alkylene moieties typically contain from about 1 to 6 carbon atoms. The cycloalkyl moieties can contain from 3 to about 10 carbon atoms, but typically contain five, six, or seven ring carbon atoms--e.g., cyclopentyl, cyclohexyl, and cycloheptyl ring structures. The aryl and arylene moieties are usually phenyl and phenylene moieties.

The hole-transporting layer can be formed of a single tertiary amine compound or a mixture of such compounds. Specifically, one may employ a triarylamine, such as a triarylamine satisfying the formula (B), in combination with a tetraaryldiamine, such as indicated by formula (D). Illustrative of useful aromatic tertiary amines are the following:

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane (TAPC)
1,1-Bis(4-di-*p*-tolylaminophenyl)-4-methylcyclohexane
1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane
1,1-Bis(4-di-*p*-tolylaminophenyl)-3-phenylpropane (TAPPP)
N,N,N',N'-tetraphenyl-4,4''-diamino-1,1':4',1'':4'',1'''-quaterphenyl
Bis(4-dimethylamino-2-methylphenyl)phenylmethane
1,4-bis[2-[4-[*N,N*-di(*p*-toly)amino]phenyl]vinyl]benzene (BDTAPVB)
N,N,N',N'-Tetra-*p*-tolyl-4,4'-diaminobiphenyl (TTB)
N,N,N',N'-Tetraphenyl-4,4'-diaminobiphenyl
N,N,N',N'-tetra-1-naphthyl-4,4'-diaminobiphenyl
N,N,N',N'-tetra-2-naphthyl-4,4'-diaminobiphenyl
N-Phenylcarbazole
4,4'-Bis[*N*-(1-naphthyl)-*N*-phenylamino]biphenyl (NPB)
4,4'-Bis[*N*-(1-naphthyl)-*N*-(2-naphthyl)amino]biphenyl (TNB)
4,4'-Bis[*N*-(1-naphthyl)-*N*-phenylamino]*p*-terphenyl
4,4'-Bis[*N*-(2-naphthyl)-*N*-phenylamino]biphenyl
4,4'-Bis[*N*-(3-acenaphthenyl)-*N*-phenylamino]biphenyl
1,5-Bis[*N*-(1-naphthyl)-*N*-phenylamino]naphthalene
4,4'-Bis[*N*-(9-anthryl)-*N*-phenylamino]biphenyl
4,4'-Bis[*N*-(1-anthryl)-*N*-phenylamino]-*p*-terphenyl

4,4'-Bis[*N*-(2-phenanthryl)-*N*-phenylamino]biphenyl
 4,4'-Bis[*N*-(8-fluoranthenyl)-*N*-phenylamino]biphenyl
 4,4'-Bis[*N*-(2-pyrenyl)-*N*-phenylamino]biphenyl
 4,4'-Bis[*N*-(2-naphthacenyl)-*N*-phenylamino]biphenyl
 5 4,4'-Bis[*N*-(2-perylenyl)-*N*-phenylamino]biphenyl
 4,4'-Bis[*N*-(1-coronenyl)-*N*-phenylamino]biphenyl
 2,6-Bis(di-*p*-tolylamino)naphthalene
 2,6-Bis[di-(1-naphthyl)amino]naphthalene
 2,6-Bis[*N*-(1-naphthyl)-*N*-(2-naphthyl)amino]naphthalene
 10 *N,N,N',N'*-Tetra(2-naphthyl)-4,4''-diamino-*p*-terphenyl
 4,4'-Bis{*N*-phenyl-*N*-[4-(1-naphthyl)-phenyl]amino}biphenyl
 2,6-Bis[*N,N*-di(2-naphthyl)amino]fluorene
 4,4',4''-tris[(3-methylphenyl)phenylamino]triphenylamine (MTDATA)
 4,4'-Bis[*N*-(3-methylphenyl)-*N*-phenylamino]biphenyl (TPD)

15 Another class of useful hole-transporting materials includes polycyclic aromatic compounds as described in EP 1 009 041. Tertiary aromatic amines with more than two amine groups may be used including oligomeric materials. In addition, polymeric hole-transporting materials can be used such as poly(*N*-vinylcarbazole) (PVK), polythiophenes, polypyrrole, polyaniline, and
 20 copolymers such as poly(3,4-ethylenedioxythiophene) / poly(4-styrenesulfonate) also called PEDOT/PSS. It is also possible for the hole-transporting layer to comprise two or more sublayers of differing compositions, the composition of each sublayer being as described above. The thickness of the hole-transporting layer can be between 10 and about 500 nm and suitably between 50 and 300 nm.

25 Light-Emitting Layer (LEL)

In addition to the light-emitting materials of this invention, additional light emitting materials may be used in the EL device, including other fluorescent materials. Other fluorescent materials may be used in the same layer as the inventive material, in adjacent layers, in adjacent pixels, or any
 30 combination.

As more fully described in U.S. Patent Nos. 4,769,292 and 5,935,721, the light-emitting layer (LEL) of the organic EL element includes a luminescent material where electroluminescence is produced as a result of electron-hole pair recombination. The light-emitting layer can be comprised of a single material, but more commonly consists of a host material doped with a guest emitting material or materials where light emission comes primarily from the emitting materials and can be of any color. The host materials in the light-emitting layer can be an electron-transporting material, as defined below, a hole-transporting material, as defined above, or another material or combination of materials that support hole-electron recombination. Fluorescent emitting materials are typically incorporated at 0.01 to 10 % by weight of the host material.

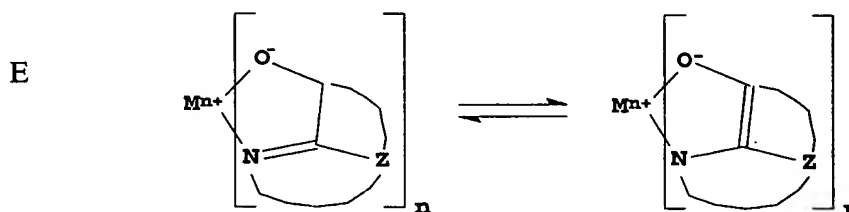
The host and emitting materials can be small non-polymeric molecules or polymeric materials such as polyfluorenes and polyvinylarylenes (e.g., poly(*p*-phenylenevinylene), PPV). In the case of polymers, small-molecule emitting materials can be molecularly dispersed into a polymeric host, or the emitting materials can be added by copolymerizing a minor constituent into a host polymer. Host materials may be mixed together in order to improve film formation, electrical properties, light emission efficiency, operating lifetime, or manufacturability. The host may comprise a material that has good hole-transporting properties and a material that has good electron-transporting properties.

An important relationship for choosing a fluorescent material as a guest emitting material is a comparison of the excited singlet-state energies of the host and the fluorescent material. It is highly desirable that the excited singlet-state energy of the fluorescent material be lower than that of the host material. The excited singlet-state energy is defined as the difference in energy between the emitting singlet state and the ground state. For non-emissive hosts, the lowest excited state of the same electronic spin as the ground state is considered the emitting state.

Host and emitting materials known to be of use include, but are not limited to, those disclosed in US 4,768,292, US 5,141,671, US 5,150,006, US

5,151,629, US 5,405,709, US 5,484,922, US 5,593,788, US 5,645,948, US 5,683,823, US 5,755,999, US 5,928,802, US 5,935,720, US 5,935,721, and US 6,020,078.

As described previously, metal complexes of 8-hydroxyquinoline and similar derivatives, also known as metal-chelated oxinoid compounds (Formula E), constitute one class of useful host compounds capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 500 nm, e.g., green, yellow, orange, and red.



wherein

10 M represents a metal;

n is an integer of from 1 to 4; and

Z independently in each occurrence represents the atoms completing a nucleus having at least two fused aromatic rings.

From the foregoing it is apparent that the metal can be monovalent, divalent, trivalent, or tetravalent metal. The metal can, for example, be an alkali metal, such as lithium, sodium, or potassium; an alkaline earth metal, such as magnesium or calcium; a trivalent metal, such aluminum or gallium, or another metal such as zinc or zirconium. Generally any monovalent, divalent, trivalent, or tetravalent metal known to be a useful chelating metal can be employed.

20 Z completes a heterocyclic nucleus containing at least two fused aromatic rings, at least one of which is an azole or azine ring. Additional rings, including both aliphatic and aromatic rings, can be fused with the two required rings, if required. To avoid adding molecular bulk without improving on function the number of ring atoms is usually maintained at 18 or less.

25 Illustrative of useful chelated oxinoid compounds are the following:

CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]

CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]

CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)

CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)-μ-oxo-bis(2-methyl-8-
5 quinolinolato) aluminum(III)

CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]

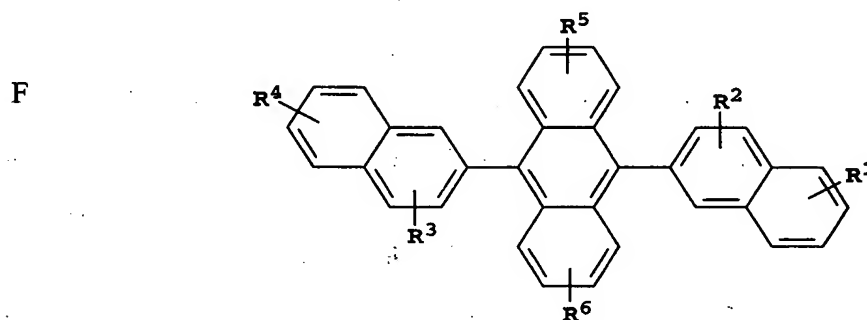
CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato)
aluminum(III)]

CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]

10 CO-8: Gallium oxine [alias, tris(8-quinolinolato)gallium(III)]

CO-9: Zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)]

As already mentioned, derivatives of 9,10-di-(2-
naphthyl)anthracene (Formula F) constitute one class of useful host materials
capable of supporting electroluminescence, and are particularly suitable for light
15 emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or
red.



wherein: R¹, R², R³, R⁴, R⁵, and R⁶ represent one or more substituents on each ring
where each substituent is individually selected from the following groups:

20 Group 1: hydrogen, or alkyl of from 1 to 24 carbon atoms;

Group 2: aryl or substituted aryl of from 5 to 20 carbon atoms;

Group 3: carbon atoms from 4 to 24 necessary to complete a fused
aromatic ring of anthracenyl; pyrenyl, or perylenyl;

Group 4: heteroaryl or substituted heteroaryl of from 5 to 24 carbon atoms as necessary to complete a fused heteroaromatic ring of furyl, thienyl, pyridyl, quinolinyl or other heterocyclic systems;

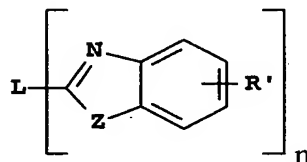
Group 5: alkoxyamino, alkylamino, or arylamino of from 1 to 24 carbon atoms; and

Group 6: fluorine, chlorine, bromine or cyano.

Illustrative examples include 9,10-di-(2-naphthyl)anthracene and 2-*t*-butyl-9,10-di-(2-naphthyl)anthracene. Other anthracene derivatives can be useful as a host in the LEL, including derivatives of 9,10-bis[4-(2,2-diphenylethenyl)phenyl]anthracene.

Benzazole derivatives (Formula G) constitute another class of useful host materials capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.

G



wherein:

n is an integer of 3 to 8;

Z is O, NR or S; and

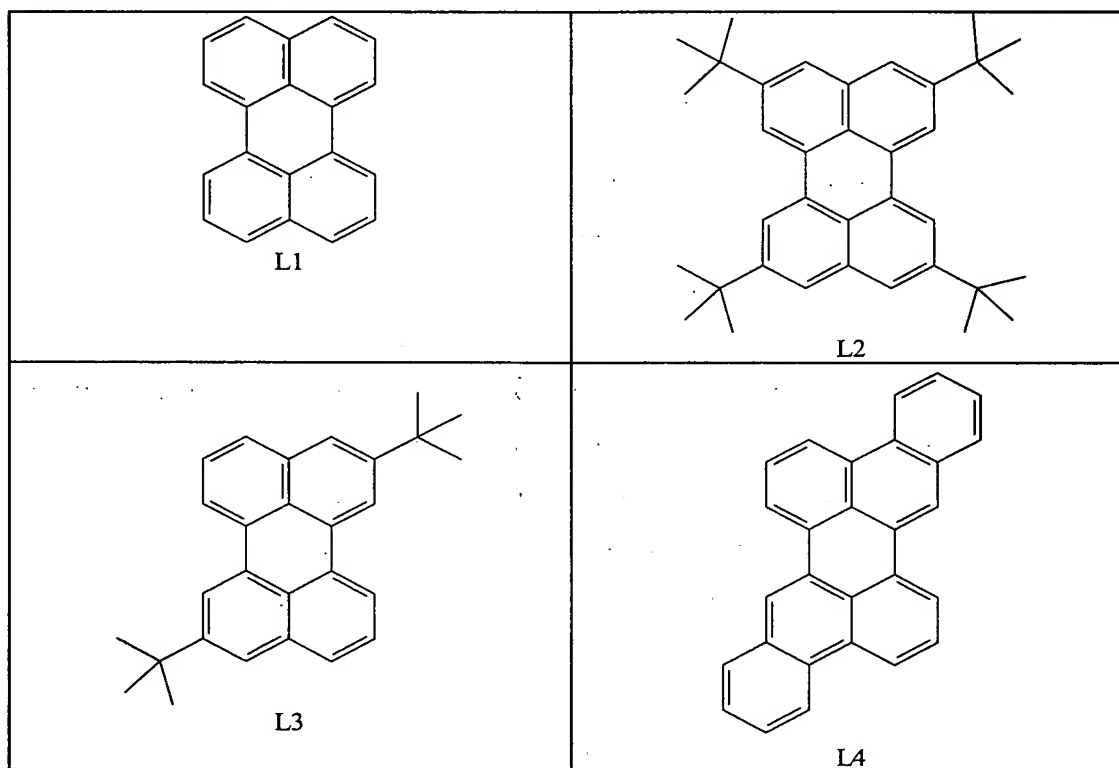
R and R' are individually hydrogen; alkyl of from 1 to 24 carbon atoms, for example, propyl, *t*-butyl, heptyl, and the like; aryl or hetero-atom substituted aryl of from 5 to 20 carbon atoms for example phenyl and naphthyl, furyl, thienyl, pyridyl, quinolinyl and other heterocyclic systems; or halo such as chloro, fluoro; or atoms necessary to complete a fused aromatic ring; and

L is a linkage unit consisting of alkyl, aryl, substituted alkyl, or substituted aryl, which connects the multiple benzazoles together. L may be either conjugated with the multiple benzazoles or not in conjugation with them. An example of a useful benzazole is 2,2',2''-(1,3,5-phenylene)tris[1-phenyl-1H-benzimidazole].

Styrylarylene derivatives as described in U.S. Patent 5,121,029 and JP 08333569 are also useful hosts for blue emission. For example, 9,10-bis[4-(2,2-

diphenylethenyl)phenyl]anthracene and 4,4'-bis(2,2-diphenylethenyl)-1,1'-biphenyl (DPVBi) are useful hosts for blue emission.

Useful fluorescent emitting materials include, but are not limited to, derivatives of anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, and quinacridone, dicyanomethylenepyrans compounds, thiopyran compounds, polymethine compounds, pyrylium and thiapyrylium compounds, fluorene derivatives, perflanthene derivatives, indenoperylene derivatives, bis(azinyl)amine boron compounds, bis(azinyl)methane compounds, and carbostyryl compounds. Illustrative examples of useful materials include, but are not limited to, the following:



L5

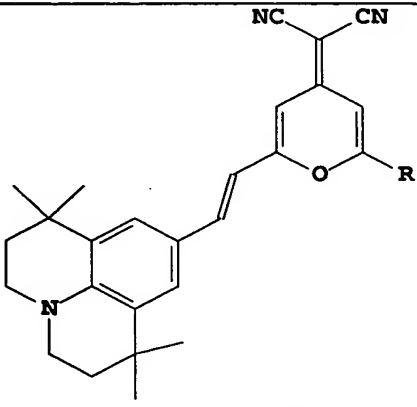
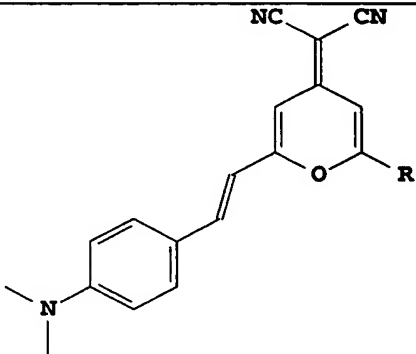
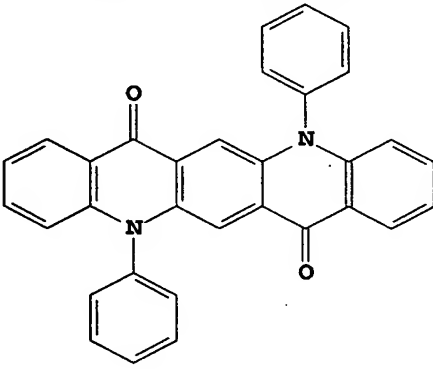
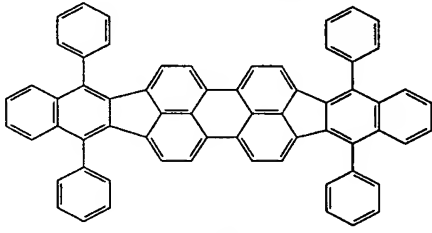
L6

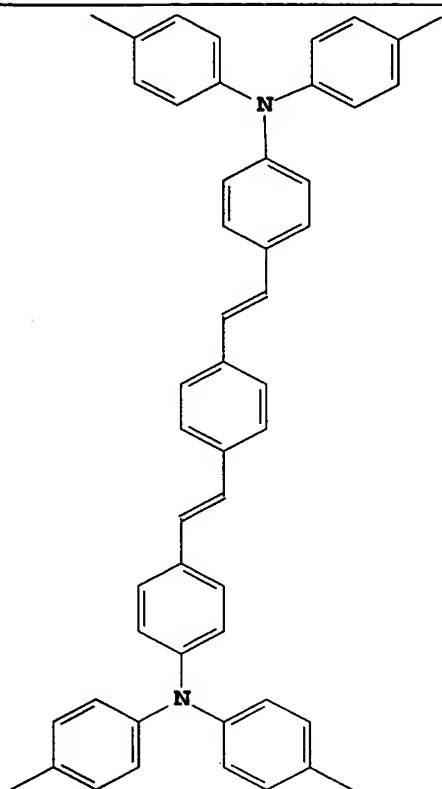
L7

L8

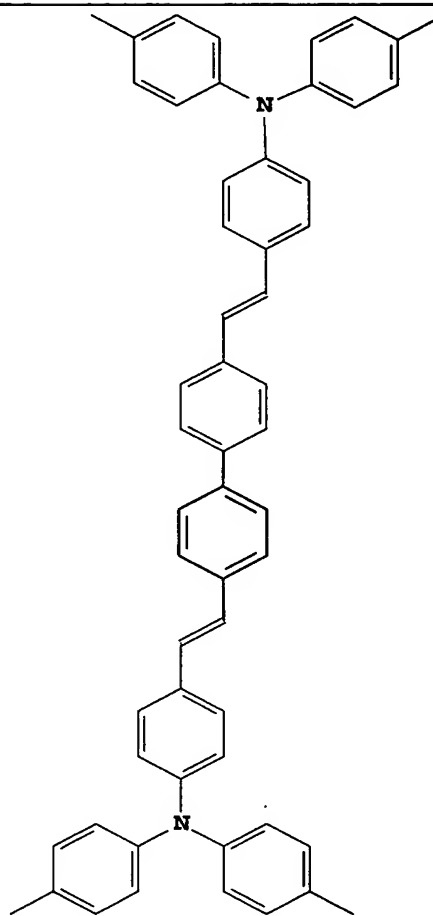
	<u>X</u>	<u>R1</u>	<u>R2</u>
L9	O	H	H
L10	O	H	Methyl
L11	O	Methyl	H
L12	O	Methyl	Methyl
L13	O	H	<i>t</i> -butyl
L14	O	<i>t</i> -butyl	H
L15	O	<i>t</i> -butyl	<i>t</i> -butyl
L16	S	H	H
L17	S	H	Methyl
L18	S	Methyl	H
L19	S	Methyl	Methyl
L20	S	H	<i>t</i> -butyl
L21	S	<i>t</i> -butyl	H
L22	S	<i>t</i> -butyl	<i>t</i> -butyl

	<u>X</u>	<u>R1</u>	<u>R2</u>
L23	O	H	H
L24	O	H	Methyl
L25	O	Methyl	H
L26	O	Methyl	Methyl
L27	O	H	<i>t</i> -butyl
L28	O	<i>t</i> -butyl	H
L29	O	<i>t</i> -butyl	<i>t</i> -butyl
L30	S	H	H
L31	S	H	Methyl
L32	S	Methyl	H
L33	S	Methyl	Methyl
L34	S	H	<i>t</i> -butyl
L35	S	<i>t</i> -butyl	H
L36	S	<i>t</i> -butyl	<i>t</i> -butyl

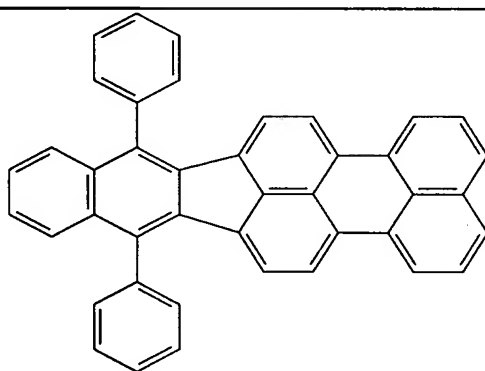
 <p> L37 L38 L39 L40 </p> <p> <u>R</u> phenyl methyl <i>t</i>-butyl mesityl </p>	 <p> L41 L42 L43 L44 </p> <p> <u>R</u> phenyl methyl <i>t</i>-butyl mesityl </p>
 <p>L45</p>	 <p>L46</p>



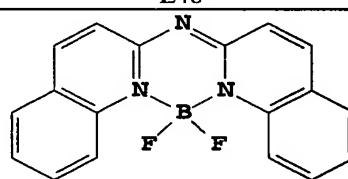
L47



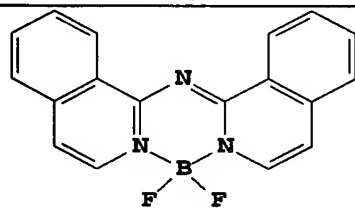
L48



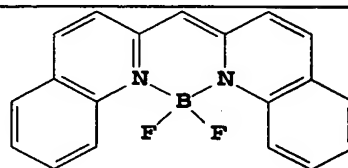
L49



L50



L51



L52

In addition to the light-emitting materials of this invention, light-emitting phosphorescent materials may be used in the EL device. For convenience, the phosphorescent complex guest material may be referred to herein as a phosphorescent material. The phosphorescent material typically includes one or more ligands, for example monoanionic ligands that can be coordinated to a metal through an sp^2 carbon and a heteroatom. Conveniently, the ligand can be phenylpyridine (ppy) or derivatives or analogs thereof. Examples of some useful phosphorescent organometallic materials include tris(2-phenylpyridinato- $N, C^{2'}$)iridium(III), bis(2-phenylpyridinato- $N, C^{2'}$)iridium(III)(acetylacetonate), and bis(2-phenylpyridinato- $N, C^{2'}$)platinum(II). Usefully, many phosphorescent organometallic materials emit in the green region of the spectrum, that is, with a maximum emission in the range of 510 to 570 nm.

Phosphorescent materials may be used singly or in combinations with other phosphorescent materials, either in the same or different layers.

Phosphorescent materials and suitable hosts are described in WO 00/57676, WO 00/70655, WO 01/41512 A1, WO 02/15645 A1, US 2003/0017361 A1, WO 01/93642 A1, WO 01/39234 A2, US 6,458,475 B1, WO 02/071813 A1, US 6,573,651 B2, US 2002/0197511 A1, WO 02/074015 A2, US 6,451,455 B1, US 2003/0072964 A1, US 2003/0068528 A1, US 6,413,656 B1, US 6,515,298 B2, US 6,451,415 B1, US 6,097,147, US 2003/0124381 A1, US 2003/0059646 A1, US 2003/0054198 A1, EP 1 239 526 A2, EP 1 238 981 A2, EP 1 244 155 A2, US 2002/0100906 A1, US 2003/0068526 A1, US 2003/0068535 A1, JP 2003073387A, JP 2003 073388A, US 2003/0141809 A1, US 2003/0040627 A1, JP 2003059667A, JP 2003073665A, and US 2002/0121638 A1.

The emission wavelengths of cyclometallated Ir(III) complexes of the type IrL_3 and IrL_2L' , such as the green-emitting *fac*-tris(2-phenylpyridinato- $N, C^{2'}$)iridium(III) and bis(2-phenylpyridinato- $N, C^{2'}$)iridium(III)(acetylacetonate) may be shifted by substitution of electron donating or withdrawing groups at appropriate positions on the cyclometallating ligand L, or by choice of different heterocycles for the cyclometallating ligand L. The emission wavelengths may also be shifted by choice of the ancillary ligand L'. Examples of red emitters are

the bis(2-(2'-benzothienyl)pyridinato- N, C^3)iridium(III)(acetylacetonate) and tris(2-phenylisoquinolino- N, C)iridium(III). A blue-emitting example is bis(2-(4,6-difluorophenyl)-pyridinato- N, C^2)iridium(III)(picolinate).

Red electrophosphorescence has been reported, using bis(2-(2'-benzo[4,5-a]thienyl)pyridinato- N, C^3) iridium (acetylacetonate) [Btp₂Ir(acac)] as the phosphorescent material (C. Adachi, S. Lamansky, M. A. Baldo, R. C. Kwong, M. E. Thompson, and S. R. Forrest, *App. Phys. Lett.*, **78**, 1622-1624 (2001)).

Other important phosphorescent materials include cyclometallated Pt(II) complexes such as cis-bis(2-phenylpyridinato- N, C^2)platinum(II), cis-bis(2-(2'-thienyl)pyridinato- N, C^3) platinum(II), cis-bis(2-(2'-thienyl)quinolino- N, C^5) platinum(II), or (2-(4,6-difluorophenyl)pyridinato- N, C^2) platinum (II) (acetylacetonate). Pt (II) porphyrin complexes such as 2,3,7,8,12,13,17,18-octaethyl-21H, 23H-porphine platinum(II) are also useful phosphorescent materials.

Still other examples of useful phosphorescent materials include coordination complexes of the trivalent lanthanides such as Tb³⁺ and Eu³⁺ (J. Kido et al., *Appl. Phys. Lett.*, **65**, 2124 (1994)).

Suitable host materials for phosphorescent materials should be selected so that transfer of a triplet exciton can occur efficiently from the host material to the phosphorescent material but cannot occur efficiently from the phosphorescent material to the host material. Therefore, it is highly desirable that the triplet energy of the phosphorescent material be lower than the triplet energy of the host. Generally speaking, a large triplet energy implies a large optical bandgap. However, the band gap of the host should not be chosen so large as to cause an unacceptable barrier to injection of charge carriers into the light-emitting layer and an unacceptable increase in the drive voltage of the OLED. Suitable host materials are described in WO 00/70655 A2; 01/39234 A2; 01/ 93642 A1; 02/074015 A2; 02/15645 A1, and US 20020117662. Suitable hosts include certain aryl amines, triazoles, indoles and carbazole compounds. Examples of desirable hosts are 4,4'- N, N' -dicarbazole-biphenyl, otherwise known as 4,4'-bis(carbazol-9-yl)biphenyl or CBP; 4,4'- N, N' -dicarbazole-2,2'-dimethyl-biphenyl, otherwise known as 2,2'-

dimethyl-4,4'-bis(carbazol-9-yl)biphenyl or CDBP; 1,3-bis(*N,N'*-dicarbazole)benzene, otherwise known as 1,3-bis(carbazol-9-yl)benzene, and poly(*N*-vinylcarbazole), including their derivatives.

Desirable host materials are capable of forming a continuous film.

5 Hole-Blocking Layer (HBL)

In addition to suitable hosts, an OLED device employing a phosphorescent material often requires at least one hole-blocking layer placed between the electron-transporting layer 111 and the light-emitting layer 109 to help confine the excitons and recombination events to the light-emitting layer comprising the host and phosphorescent material. In this case, there should be an energy barrier for hole migration from the host into the hole-blocking layer, while electrons should pass readily from the hole-blocking layer into the light-emitting layer comprising a host and a phosphorescent material. The first requirement entails that the ionization potential of the hole-blocking layer be larger than that of the light-emitting layer 109, desirably by 0.2 eV or more. The second requirement entails that the electron affinity of the hole-blocking layer not greatly exceed that of the light-emitting layer 109, and desirably be either less than that of light-emitting layer or not exceed that of the light-emitting layer by more than about 0.2 eV.

20 When used with an electron-transporting layer whose characteristic luminescence is green, such as an Alq-containing electron-transporting layer as described below, the requirements concerning the energies of the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) of the material of the hole-blocking layer frequently result in a characteristic luminescence of the hole-blocking layer at shorter wavelengths than that of the electron-transporting layer, such as blue, violet, or ultraviolet luminescence. Thus, it is desirable that the characteristic luminescence of the material of a hole-blocking layer be blue, violet, or ultraviolet. It is further desirable, but not absolutely required, that the triplet energy of the hole-blocking material be greater than that of the phosphorescent material. Suitable hole-blocking materials are described in WO 00/70655A2 and WO 01/93642 A1. Two examples of useful

hole-blocking materials are bathocuproine (BCP) and bis(2-methyl-8-quinolinolato)(4-phenylphenolato)aluminum(III) (BALq). The characteristic luminescence of BCP is in the ultraviolet, and that of BALq is blue. Metal complexes other than BALq are also known to block holes and excitons as described in US 20030068528. In addition, US 20030175553 A1 describes the use of *fac*-tris(1-phenylpyrazolato-*N,C*^{2'})iridium(III) (Irppz) for this purpose.

When a hole-blocking layer is used, its thickness can be between 2 and 100 nm and suitably between 5 and 10 nm.

Electron-Transporting Layer (ETL)

Desirable thin film-forming materials for use in forming the electron-transporting layer 111 of the organic EL devices of this invention are metal-chelated oxinoid compounds, including chelates of oxine itself (also commonly referred to as 8-quinolinol or 8-hydroxyquinoline). Such compounds help to inject and transport electrons, exhibit high levels of performance, and are readily fabricated in the form of thin films. Exemplary of contemplated oxinoid compounds are those satisfying structural formula (E), previously described.

Other electron-transporting materials suitable for use in the electron-transporting layer 111 include various butadiene derivatives as disclosed in US 4,356,429 and various heterocyclic optical brighteners as described in US 4,539,507. Benzazoles satisfying structural formula (G) are also useful electron transporting materials. Triazines are also known to be useful as electron transporting materials.

If both a hole-blocking layer and an electron-transporting layer 111 are used, electrons should pass readily from the electron-transporting layer 111 into the hole-blocking layer. Therefore, the electron affinity of the electron-transporting layer 111 should not greatly exceed that of the hole-blocking layer. Desirably, the electron affinity of the electron-transporting layer should be less than that of the hole-blocking layer or not exceed it by more than about 0.2 eV.

If an electron-transporting layer is used, its thickness may be between 2 and 100 nm and suitably between 5 and 20 nm.

Other Useful Organic Layers and Device Architecture

In some instances, layers 109 through 111 can optionally be collapsed into a single layer that serves the function of supporting both light emission and electron transportation. The hole-blocking layer, when present, and layer 111 may also be collapsed into a single layer that functions to block holes or excitons, and supports electron transport. It also known in the art that emitting materials may be included in the hole-transporting layer 107. In that case, the hole-transporting material may serve as a host. Multiple materials may be added to one or more layers in order to create a white-emitting OLED, for example, by combining blue- and yellow-emitting materials, cyan- and red-emitting materials, or red-, green-, and blue-emitting materials. White-emitting devices are described, for example, in EP 1 187 235, US 20020025419, EP 1 182 244, US 5,683,823, US 5,503,910, US 5,405,709, and US 5,283,182 and can be equipped with a suitable filter arrangement to produce a color emission.

This invention may be used in so-called stacked device architecture, for example, as taught in US 5,703,436 and US 6,337,492.

Deposition of Organic Layers

The organic materials mentioned above are suitably deposited by any means suitable for the form of the organic materials. In the case of small molecules, they are conveniently deposited through sublimation or evaporation, but can be deposited by other means such as coating from a solvent together with an optional binder to improve film formation. If the material is a polymer, solvent deposition is usually preferred. The material to be deposited by sublimation or evaporation can be vaporized from a sublimator "boat" often comprised of a tantalum material, e.g., as described in US 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow masks, integral shadow masks (US 5,294,870), spatially-defined thermal dye transfer from a donor sheet (US 5,688,551, US 5,851,709 and US 6,066,357) or an inkjet method (US 6,066,357).

Encapsulation

Most OLED devices are sensitive to moisture or oxygen, or both, so they are commonly sealed in an inert atmosphere such as nitrogen or argon, along with a desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates. Methods for encapsulation and desiccation include, but are not limited to, those described in U.S. Patent No. 6,226,890. In addition, barrier layers such as SiO_x, Teflon, and alternating inorganic/polymeric layers are known in the art for encapsulation. Any of these methods of sealing or encapsulation and desiccation can be used with the EL devices constructed according to the present invention.

Optical Optimization

OLED devices of this invention can employ various well-known optical effects in order to enhance their emissive properties if desired. This includes optimizing layer thicknesses to yield maximum light transmission, providing dielectric mirror structures, replacing reflective electrodes with light-absorbing electrodes, providing anti-glare or anti-reflection coatings over the display, providing a polarizing medium over the display, or providing colored, neutral density, or color-conversion filters over the display. Filters, polarizers, and anti-glare or anti-reflection coatings may be specifically provided over the EL device or as part of the EL device.

Embodiments of the invention can provide advantageous features such as higher luminous yield, lower drive voltage, and higher power efficiency, improved operational stability, or reduced sublimation temperatures. Embodiments of the compounds useful in the invention can provide a wide range of hues including those useful in the emission of white light (directly or through filters to provide multicolor displays). Embodiments of the invention can also provide an area lighting device.

The invention and its advantages can be better appreciated by the following examples.

Synthetic Example-Preparation of Inv-1

- 5 a) Preparation of 9-(2-naphthyl)anthracene. 9-Bromoanthracene (12g, 46mmol, 1eq) and 2-naphthalenboronic acid (8.0g, 46mmol, 1 eq) were combined in 100ml of toluene and the resulting mixture degassed by sonication for about 15min. Bis(triphenylphosphine) palladiumdichloride (0.110g, 0.095 mmol, 0.2%) was added and the resulting mixture was thoroughly stirred under nitrogen while 100ml 2M Na₂CO₃ were added and the mixture heated to reflux via heating mantle. The reaction was left to reflux overnight. The reaction was cooled to room temperature at which time solid began to precipitate. The organic solid was isolated by filtration, washed with water, then air dried to yield 11.4g (80%). Additional extraction of the organic layer with methylene chloride followed by drying over MgSO₄ and concentration, yielded another 2g of product, for a total of 94% yield.
- 10 b) Preparation of 9-bromo, 10-(2-Naphthyl)anthracene. 9-(2-Naphthyl)anthracene (14g, 48 mmol, 1 eq) and N-bromosuccinimide (8.9g, 50 mmol, 1.05 eq) were combined with 140ml CH₂Cl₂ in a 500ml round bottom flask. The mixture was stirred at room temperature under nitrogen in the presence of light from a 100W lamp and the mixture quickly became homogeneous. Reaction was complete after 3h, as indicated by TLC (P950:CH₂Cl₂ / 9:1). Approximately half the solvent volume was stripped off just until solid started to precipitate. Then, enough acetonitrile was added with heating to dissolve the solid. Additional CH₂Cl₂ was then stripped off just to the point where solid began to precipitate. The solution was cooled and left to recrystallize. The resulting solid was isolated by filtration, washed with a small amount of acetonitrile, and dried to yield 17 g (92%).
- 15 c) Preparation of 9-(trimethylsilylethynyl)-10-(2-Naphthyl)anthracene. 9-bromo-10-(2-Naphthyl)anthracene (24.7g, 74mmol, 1 eq) was combined with copper(I)iodide (0.28g, 1.48mmol, 2eq %), and (bistriphenylphosphine)palladium(II)dichloride (0.28g, 0.4mmol,
- 20
- 25
- 30

0.5eq%) in 220mL of degassed toluene. 1,8-Diazabicyclo[5.4.0]undec-7-ene (DBU) was added in one portion (16.6mL, 111mmol, 1.5eq) and the mixture was warmed up. Then TMS acetylene was added (14mL, 99mmol, 1.3eq) in one portion and the resulting mixture quickly brought to reflux. Reaction was complete in 1h. The mixture was cooled, and solids were removed by filtration, and washed with isopropyl ether to recover all product. The filtrate was concentrated and the residue was passed through a silica gel plug to remove baseline impurities (P950:CH₂Cl₂/95:5). The crude product was recovered in 96% yield (25g) and was used in the subsequent step without further purification.

d) Preparation of 9-ethynyl-10-(2-Naphthyl)anthracene. To a suspension of 9-(trimethylsilylethynyl)-10-(2-Naphthyl)anthracenes (25g, 71.6mmol, 1eq) in 250mL MeOH under nitrogen, 8g (143mmol, 2eq) of solid KOH were added. The resulting mixture was gently heated to 60 °C for 2h, when reaction was complete. The product was isolated by filtration (it had precipitated out of the reaction mixture). The filtrate was concentrated, cooled, and the precipitated product was isolated again by filtration. Two crops were recovered: 7.7g of clean product and 7.1g of product containing a baseline impurity.

e) Preparation of ethynyl bis(phenylanthracene). The 9-bromo-10-(2-Naphthyl)anthracenes (3.5g, 1.16mmol, 0.9eq) was combined with a 12mmol solution of 9-ethynyl-10-(2-Naphthyl)anthracene (12mmol, in CH₂Cl₂) and 50mL of Et₃N, under nitrogen. To the solution, CuI (23mg, 1eq %) PPh₃ (63mg, 2eq %) and (PPh₃)₂PdCl₂ (60mg, 0.7eq %) were added in one portion, and the resulting mixture was brought to reflux. Methylene chloride was removed via Dean Stark. After about 2h of reflux, solid precipitated out, and TLC indicated the disappearance of the ethynyl starting material, and a very small amount of the bromo starting material present. The product was isolated by filtration from the cooled reaction mixture, and TLC indicated a very

clean material, free of starting materials. More product had precipitated out in the filtrate and it was recovered by one more filtration. The two batches of solid were identical and were combined to yield a total of 6.7g of clean crude material (1st crop 6.22g, 2nd crop from mother liquor 0.49g). The crude material was sublimed at 240-245 °C.

Device Examples 1-5 – EL Device Fabrication

An EL device (Sample 1) satisfying the requirements of the invention was constructed in the following manner:

- 10 1. A glass substrate coated with an 85 nm layer of indium-tin oxide (ITO) as the anode was sequentially ultrasonicated in a commercial detergent, rinsed in deionized water, degreased in toluene vapor and exposed to oxygen plasma for about 1 min.
- 15 2. Over the ITO was deposited a 1 nm fluorocarbon (CF_x) hole-injecting layer (HIL) by plasma-assisted deposition of CHF₃.
3. A hole-transporting layer (HTL) of *N,N'*-di-1-naphthyl-*N,N'*-diphenyl-4, 4'-diaminobiphenyl (NPB) having a
20 thickness of 75 nm was then evaporated from a tantalum boat.
4. A 20 nm light-emitting layer (LEL) of 2-*t*-butyl-9,10-di-(2-naphthyl)anthracene (TBADN) and Inv-1 (1.0 wt%) were
25 then deposited onto the hole-transporting layer. These materials were also evaporated from tantalum boats.
5. A 40 nm electron-transporting layer (ETL) of tris(8-quinolinolato)aluminum (III) (AlQ₃) was then deposited
 onto the light-emitting layer. This material was also
 evaporated from a tantalum boat.
- 30 6. On top of the AlQ₃ layer was deposited a 220 nm cathode formed of a 10:1 volume ratio of Mg and Ag.

The above sequence completed the deposition of the EL device. The device was then hermetically packaged in a dry glove box for protection against ambient environment.

Additional EL devices were fabricated with different levels of Inv-1, in this case, levels of Inv-1 greater than 0.5% were found to give desirable results. EL devices, Examples 2 and 3, incorporating Inv-1 were fabricated in an identical manner as Example 1, except Inv-1 was used at the levels indicated in the Table 1. Example 4 was prepared in the same manner as Example 1, except Inv-1 was omitted. Example 5 was prepared in the same manner as Example 2, except Inv-1 was replaced with 2,5,8,11-tetra-*t*-butyl perylene (TBP), for comparison purposes. The cells thus formed in Examples 1-5 were tested for efficiency in the form of luminance yield (cd/A) measured at 20 mA/cm². CIE color x and y coordinates were determined. The luminance loss was measured by subjecting the cells to a constant current density of 20mA/cm² at 25°C. Stability for use in a display device is desirably less than about 40% loss after about 300 hours under these accelerated aging conditions. The cells thus formed were tested for efficiency and color at an operating current of 20 mA/cm² and the results are reported in Table 1 in the form of output efficiency (W/A), luminance yield (cd/A), maximum wavelength (λ_{max}) of emission and CIE (Commission Internationale de L'Eclairage) coordinates. The cells were tested for stability by operating the cells at 20 mA/cm² for 334 h at room temperature. The luminance of the cell after operating for this time relative to the initial luminance is listed in Table 1 as a percentage under the column titled 'Stability'. The luminance of each cell was then plotted versus time. The resulting plot was normalized to 1 and then mathematically fitted to a stretched exponential equation. This equation was then used to determine the amount of time the cell could operate before its luminance would decrease 50% relative to the initial luminance. This value is reported in Table 1 as 'T50 extrapolated'.

Table 1. Evaluation Results for EL devices 1-5.

Example	Inv-1 Level (%)	TBP Level (%)	Efficiency (W/A)	Yield (cd/A)	CIE _x	CIE _y	λ_{max} (nm)	Stability (%)	T50 extrapolated	Type
1	1.00	0.00	0.048	6.19	0.244	0.559	504	98.3	15067 h	Invention
2	1.50	0.00	0.039	5.33	0.267	0.584	508	97.5	10857 h	Invention
3	2.00	0.00	0.039	5.38	0.266	0.590	508	96.7	13457 h	Invention
4	0.00	0.00	0.034	1.57	0.166	0.142	448	79.3	1093 h	Comparison
5	0.00	1.00	0.039	2.32	0.150	0.208	464	92.5	2867 h	Comparison

As can be seen from Table 1, all tested EL devices incorporating the light-emitting material of the invention exhibit a blue-green electroluminescence. Devices containing the inventive material show improved stability relative to a device not containing the material (Example 4) or one containing a blue-light-emitting material (Example 5).

Device Examples 6-9

Devices 6-9 were fabricated in the same manner as described above except that, the Alq emitting layer is doped with a combination of two dopants (the emitting DPQA dopant and the stabilizing Inv-1 dopant, the exact dopant percentages used are reported in Table 2. An EL device (Example 6) satisfying the requirements of the invention was constructed in the following manner:

1. A glass substrate coated with an 85 nm layer of indium-tin oxide (ITO) as the anode was sequentially ultrasonicated in a commercial detergent, rinsed in deionized water, degreased in toluene vapor and exposed to oxygen plasma for about 1 min.
2. Over the ITO was deposited a 1 nm fluorocarbon (CF_x) hole-injecting layer (HIL) by plasma-assisted deposition of CHF₃.
3. A hole-transporting layer (HTL) of *N,N'*-di-1-naphthyl-*N,N'*-diphenyl-4, 4'-diaminobiphenyl (NPB) having a thickness of 75 nm was then evaporated from a tantalum boat.

4. A 37.5 nm light-emitting layer (LEL) of tris(8-quinolinolato)aluminum (III) (AlQ_3), light-emitting material 5b (DPQA, 0.60 wt%), and/or Inv-1 (0.50%) were then deposited onto the hole-transporting layer. These materials were also evaporated from tantalum boats.
5. A 37.5 nm electron-transporting layer (ETL) of tris(8-quinolinolato)aluminum (III) (AlQ_3) was then deposited onto the light-emitting layer. This material was also evaporated from a tantalum boat.
6. On top of the AlQ_3 layer was deposited a 220 nm cathode formed of a 10:1 volume ratio of Mg and Ag.

The above sequence completed the deposition of the EL device. The device was then hermetically packaged in a dry glove box for protection against ambient environment.

EL devices, Samples 7 and 8 incorporating Inv-1 were fabricated in an identical manner as Sample 6, except Inv-1 was used at the levels indicated in the Table 2. Sample 9 was prepared in the same manner as Sample 6 except Inv-1 was omitted. The cells thus formed were tested for efficiency and color at an operating current of 20 mA/cm^2 and the results are reported in Table 2. The cells were tested for stability by operating the cells at 40 mA/cm^2 for 640 h at room temperature. The luminance after operating for this time relative to the initial luminance is listed in Table 2 as a percentage. The luminance of each cell was then plotted versus time. The resulting plot was normalized to 1 and then mathematically fitted to a stretched exponential equation. This equation was then used to determine the amount of time the cell could operate before its luminance would decrease 50% relative to the initial luminance. This value is reported in Table 1 as 'T50 extrapolated'.

4b
(DPQA)

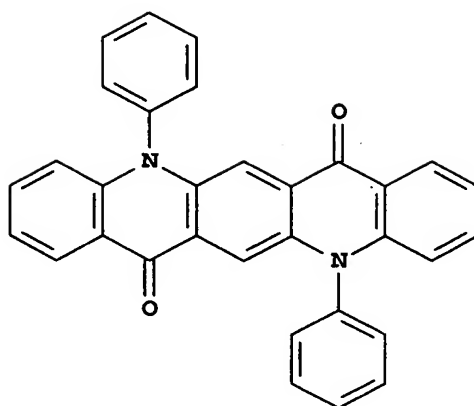


Table 2. Evaluation Results for EL devices 6-9.

Example	Inv-1 Level (%)	4b Level %	Efficiency (W/A)	Yield (cd/A)	CIE _x	CIE _y	Emission λ_{max} (nm)	Stability (%)	T50 extrapolated	Type
6	0.50	0.6	0.047	7.84	0.310	0.641	528	72	2340 h	Invention
7	1.00	0.6	0.045	7.42	0.314	0.639	528	76	4014 h	Invention
8	1.50	0.6	0.039	6.51	0.320	0.634	528	77	5338 h	Invention
9	0.00	0.6	0.049	8.39	0.308	0.648	528	52	934 h	Comparison

As can be seen from Table 2, all tested EL devices incorporating the material of the invention exhibit improved stability relative to a device not containing the material.

Device Examples 10-13 – EL Device Fabrication

EL devices 10-13 was fabricated in an identical manner as Examples 6-9, except light-emitting material 4b was replaced with 4a at a level of 0.5%, and Inv-1 was used at the levels indicated in the Table 3. The cells thus formed were tested for efficiency and color at an operating current of 20 mA/cm² and the results are reported in Table 3. The cells were tested for stability by operating the cells at 40 mA/cm² for 593 h at room temperature. The luminance after operating for this time relative to the initial luminance is listed in Table 3 as a percentage. The luminance of each cell was then plotted versus time. The resulting plot was normalized to 1 and then mathematically fitted to a stretched exponential equation. This equation was then used to estimate the amount of time

the cell could operate before its luminance would decrease 50% relative to the initial luminance. This value is reported in Table 1 as 'T50 extrapolated'.

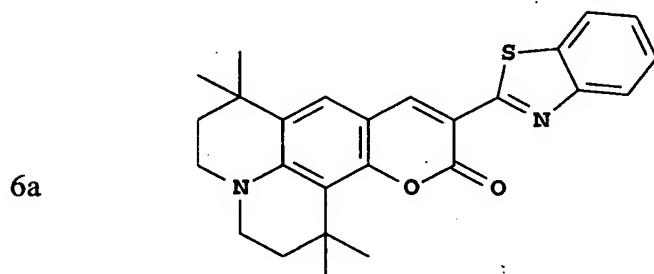


Table 3. Evaluation Results for EL devices 10-13.

Example	Inv-1 Level (%)	6a Level %	Efficiency (W/A)	Yield (cd/A)	CIE _x	CIE _y	Emission λ_{max} (nm)	Stability (%)	T50 extrapolated	Type
10	0.50	0.5	0.052	8.07	0.299	0.634	520	73	1919 h	Invention
11	1.00	0.5	0.045	7.16	0.315	0.628	520	76	2579 h	Invention
12	1.50	0.5	0.043	6.76	0.323	0.624	524	75	2163 h	Invention
13	0.00	0.5	0.047	7.25	0.290	0.633	520	55	732 h	Comparison

As can be seen from Table 3, all tested EL devices incorporating the material of the invention exhibit improved stability relative to a device not containing the material.

Device Example 14-18

EL devices 14-18 were fabricated in an identical manner as Examples 10-13, except light-emitting material 5a was incorporated at a level of 1.0% instead of 0.5%. The cells thus formed were tested for efficiency and color at an operating current of 20 mA/cm² and the results are reported in Table 4. The cells were tested for stability by operating the cells at 40 mA/cm² for 342 h at room temperature. The luminance left after operating for this time relative to the initial luminance is listed in Table 4 as a percentage.

Table 4. Evaluation Results for EL devices 10-14.

Example	Inv-1 Level (%)	5a Level %	Efficiency (W/A)	Yield (cd/A)	CIE _x	CIE _y	Emission λ_{max} (nm)	Stability (%)	Type
14	0.50	1.0	0.057	9.15	0.298	0.639	520	76	Invention
15	1.00	1.0	0.048	7.68	0.309	0.633	520	83	Invention
16	1.50	1.0	0.046	7.37	0.313	0.632	524	83	Invention
17	3.00	1.0	0.041	6.61	0.326	0.624	524	84	Invention
18	0.00	1.0	0.057	9.07	0.293	0.642	520	66	Comparison

As can be seen from Table 4, all tested EL devices incorporating the material of the invention exhibit improved stability relative to a device not containing the material.

Device Examples 20-22

An EL device satisfying the requirements of the invention was constructed in the same manner as Examples 6-9, at various levels of Inv-1 and various levels of DPQA (both levels are indicated in Table 5)

The cells thus formed were tested for efficiency and color at an operating current of 20 mA/cm² and the results are reported in Table 5. The cells were tested for stability by operating the cells at 40 mA/cm² for 640 h at room temperature. The luminance after operating for this time relative to the initial luminance is listed in Table 5 as a percentage. The luminance of each cell was then plotted versus time. The resulting plot was normalized to 1 and then mathematically fitted to a stretched exponential equation. This equation was then used to estimate the amount of time the cell could operate before its luminance would decrease 50% relative to the initial luminance. This value is reported in Table 1 as 'T50 extrapolated'.

Table 5. Evaluation Results for EL devices 20-22.

Example	Inv-1 Level (%)	DPQA Level (%)	Efficiency (W/A)	CIE _x	CIE _y	Emission λ_{max} (nm)	Stability (%)	T50 Extrapolated	Type
20	1.0	0.0	0.039	0.315	0.612	516	82	4042 h	Invention
21	1.5	0.0	0.035	0.324	0.614	520	83	4428 h	Invention
22	0.0	0.6	0.049	0.308	0.648	528	52	940 h	Comparison

As can be seen from Table 5, EL devices incorporating the material of the invention exhibit offer improved stability relative to a device containing the alternative light-emitting material DPQA, by as much as 5X.

5 The entire contents of the patents and other publications referred to in this specification are incorporated herein by reference. The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

101	Substrate
103	Anode
105	Hole-Injecting layer (HIL)
107	Hole-Transporting layer (HTL)
109	Light-Emitting layer (LEL)
111	Electron-Transporting layer (ETL)
113	Cathode